

## WAVELET MODULATED Z-SOURCE INVERTER

K. SHIREESHA<sup>1</sup>, K. ANURADHA<sup>2</sup> & CH. MANJEERA<sup>3</sup>

<sup>1</sup>Research Scholar, Department of EEE, VN RVJIET, Hyderabad, Telangana, India

<sup>2,3</sup>Professor, Department of EEE, VN RVJIET, Hyderabad, Telangana, India

### ABSTRACT

Now a days new technologies are being emerging, so by using new concept of wavelet function, the new modulation strategy is implemented for triggering the switches of the inverter. The wavelet function has different members in it by using this new concept i.e., this concept does not involve in carrier wave. Only the reference signal is modulated. The switching sequence depends on the two sampling periods which is taken from the wavelet family and by using the MATLAB coding the switching sequence is given to inverter. Thus these MATLAB coding is joined with the simulink to get the output. Simulation results show that WM based impedance network inverter produces smoother current output, better output voltage, and lesser Total Harmonic Distortion (THD) as compared with the other modulation techniques.

**KEYWORDS:** Non-Uniform Recurrent Sampling, Conventional Pulse Width Modulated Inverter (PWM), Z-Source Pulse Width Modulation (ZPWM), Wavelet Modulated Inverter (WM), Wavelet Modulated Z-Source Inverter

### NOMENCLATURE

|                |   |
|----------------|---|
| $\omega_r$     | Angular frequency $S_r(t)$                                |
| $S_r(t)$       | Sinusoidal reference modulated signal                     |
| $\dot{S}_r(t)$ | First derivative of sinusoidal reference modulated signal |

### INTRODUCTION

Inverters have many applications in the power electronic converters that convert DC input to AC output by triggering the switches of the circuit. The switching can be done through many ways. One method is done by comparing the carrier based with the reference wave in a sequential manner and other is done through only the reference signal. Rather than going for the higher levels of inverter going for new concept will reduce the cost and increase the efficiency.

Now a new concept of wavelet function is useful for switching on the inverter. One of the wavelet member is taken for the implementation of the switching of the inverter. The haar wavelet is taken for calculating the switching timings. This will use the reference signal and then it will be modulating the signal by the use of the two sampling period[1]. These will show that the THD obtained by them will be less when compared to the other techniques. Wavelet modulated technique produces better results and these are given to the Z-Source inverter for better performance.

The Z-Source inverter is mainly used rather than the conventional inverter due to its dual nature of both bucking and boosting of output voltage by using the impedance network present in it[6]. Then, by grouping these wavelet sampling to the Z-Source inverter will give better results when compare to the other techniques.

## CONVENTIONAL PWM INVERTER

Basically modulation techniques are carrier based and carrier less based method. PWM with carrier wave compared with the reference wave gives the ON and OFF states of the switches. When  $V_{carrier} > V_{reference}$  the switches 1 and 2 are ON and when  $V_{carrier} < V_{reference}$ , the switches 3 and 4 are ON.

The modulation factor  $M_a$ ,

$$M_a = \frac{|V_{carrier}|}{|V_{reference}|}$$

And the standardized frequency modulation index is,

$$M_f = \frac{f_{reference}}{f_{carrier}}$$

The harmonic distortion are much higher when compared with the space vector PWM and wavelet modulated inverter.

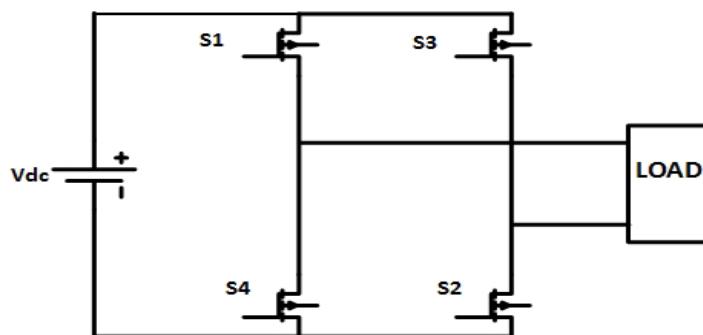


Figure 1: Single Phase Full-Bridge Inverter

## Z-SOURCE INVERTER

The special type of arrangement of inductor and capacitor in a cross linked manner is known as impedance network. That impedance network is connected across the input supply and the inverter. There will be two states like shoot-through and non shoot-through. In shoot-through state the short circuit of inverter takes place and the output voltage is zero. Due to that inverter may damage. This can be prevented by using the impedance network in between the source and inverter.

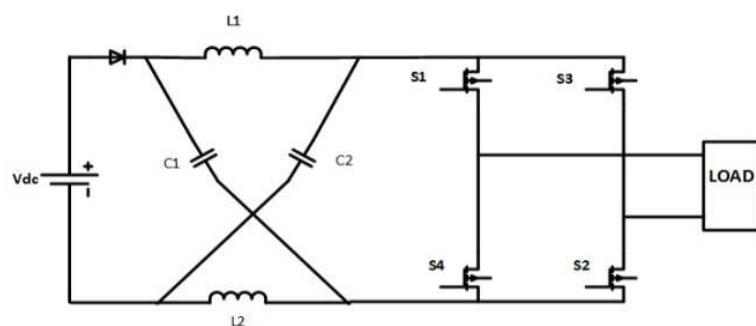


Figure 2: Z-Source Inverter

## MATHEMATICAL CALCULATION OF IMPEDANCE NETWORK IN Z-SOURCE INVERTER

Let us consider a period of  $T_0$  which indicates the shoot-through period occurs in between 0 to  $t_1$  and a period  $T_1$  which indicates the non shoot-through period occurs in between  $t_2$  to  $t_1$ . From the figure 3 and figure 4, we can evaluate the output voltage of the inverter.

The shoot-through state mathematical equations are as follows,

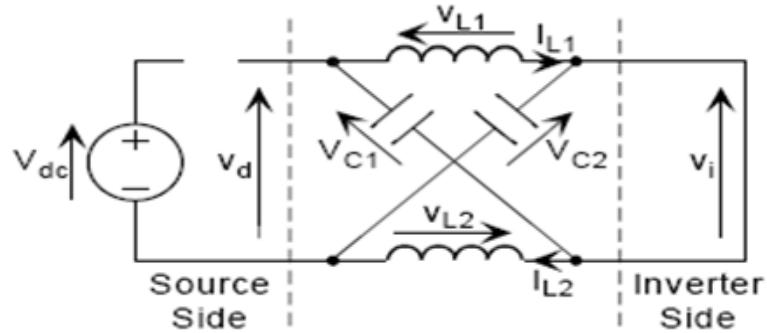


Figure 3: Equivalent Shoot-Through Circuit

$$V_{L1} = V_{L2} = v_L = V_{C1} = V_{C2} = V_C \quad (1)$$

$$V_d = v_L + V_C = 2V_C \quad (2)$$

$$v_i = 0 \quad (3)$$

The non shoot-through mathematical equations are as follows,

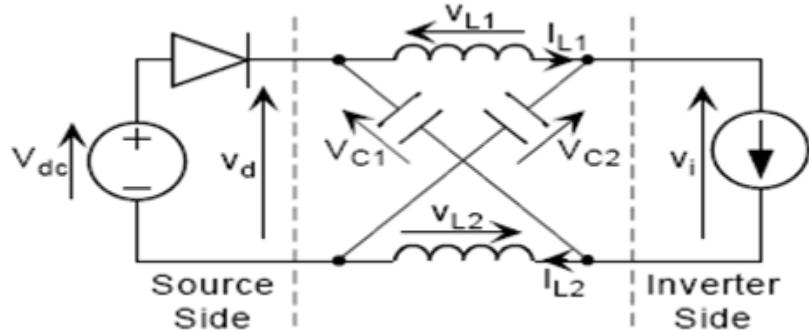


Figure 4: Equivalent Non Shoot-Through Circuit

$$v_L = V_{dc} - V_C \quad (4)$$

$$v_d = V_{dc} \quad (5)$$

$$v_i = V_C - v_L = 2V_C - V_{dc} \quad (6)$$

Then, average voltage across inductor in time duration is,

$$\int_0^T v_L dt = 0 \quad (7)$$

Now dividing the equation (7) into two regions,

$$\int_0^{t_1} v_L dt + \int_{t_1}^{t_2} v_L dt = 0 \quad (8)$$

We know that during the period of 0 to  $t_1$  there is a shoot-through operation for  $T_0$  and voltage across the inductor is  $V_C$  from equ(1) and during the period of  $t_1$  to  $t_2$  there is a non shoot-through period for  $T_1$ . The voltage across inductor during that period is  $V_{dc} - V_C$  from equ(4).

Substituting  $V_L$  values from equ(1) and equ(4) in equ(8), we get

$$\int_0^{t_1} V_C dt + \int_{t_1}^{t_2} (V_{dc} - V_C) dt = 0 \quad (9)$$

$$V_C(t_1-0) + (V_{dc} - V_C)(t_2-t_1) = 0 \quad (10)$$

The period from  $t_1$  to 0 is represented as  $T_0$  and the period from  $t_2$  to  $t_1$  represented as  $T_1$ .

Thus,

$$V_C(T_0) + (V_{dc} - V_C)(T_1) = 0$$

$$V_C(T_0 - T_1) + V_{dc}T_1 = 0$$

$$V_C = \frac{T_1}{T_1 - T_0} V_{dc} \quad (11)$$

Peak dc voltage across phase leg,

$$v_i = 2V_C - V_{dc}$$

$$v_i = [2(\frac{T_1}{T_1 - T_0}) - 1]V_{dc}$$

$$v_i = \frac{1}{1 - \frac{2T_0}{T_1}} V_{dc}$$

$$v_i = B V_{dc} \quad (12)$$

Where factor B is the boosting factor. This is the factor responsible for bucking and boosting of the output voltage.

Thus, Peak ac voltage across conventional voltage is,

$$V_x = M \frac{v_i}{2} \quad (13)$$

Thus,

$$V_x = M * \frac{B V_{dc}}{2}$$

Where M is the modulating index

## SWITCHING SCHEME ORDER

The switching state in active {10} represent the positive output voltage. The switching state in active {01} represents the negative output voltage. The 3<sup>rd</sup> and 4<sup>th</sup> switching state gives the output voltage zero i.e., upper or lower two switches are in ON condition. The next 3 stages are the shoot through stage in this output voltage will be zero and in this the phase leg will be shorted so that output across the inverter will be zero.

**Table 1: Switching Scheme of Z-Source Inverter**  
**S1 is Complement of  $\sim S1$**   
**S3 is Complement of  $\sim S3$**

| State           | S1 | S4        | S3 | S2        |
|-----------------|----|-----------|----|-----------|
| Active{10}      | 1  | 0         | 0  | 1         |
| Active{01}      | 0  | 1         | 1  | 0         |
| Null{00}        | 0  | 1         | 0  | 1         |
| Null{00}        | 1  | 0         | 1  | 0         |
| Shoot through-1 | 1  | 1         | S3 | $\sim S3$ |
| Shoot through-2 | S1 | $\sim S1$ | 1  | 1         |
| Shoot through-3 | 1  | 1         | 1  | 1         |

## WAVELET MODULATED INVERTER

The reference modulating indication of  $S_r(t)$  is having same frequency as that by inverter output. The method of the wavelet modulated mode is splitted into 2 parts, which is as follows,

- Generating a non-uniform repeated sampling of period  $T_m = (1/f_m)$ , where  $f_m$  is the frequency of reference signal  $S_r(t)$ . These are framed by dilated and rearrange version of scale based function and are grouped into two representative as  $T_{d1}$  and  $T_{d2}$ .
- Generating the pulses that are shifted version and rearranging version of scaling function.

The wavelet modulated technique can be done through following lines:

**Step 1:** Set the scale  $j_a=1$  and equate  $Y_a=1$  and index of sample group  $d_a=0$ .

**Step 2:** Produce one trial at  $T_{d1}=(d_a+2^{-(j_a+1)}) \cdot \frac{T_m}{100}$  and another trial at  $T_{d2}=(d_a+1-2^{-(j_a+1)}) \cdot \frac{T_m}{100}$ .

**Step 3:** Create an ON switching pulse over the period of carry for sample group  $d_a$ .

**Step 4:** Evaluate derivative  $S'_r(t)|_{T_{d2}}$  as:

If  $S'_r(T_{d2}) > 0$ , scale  $j_a=j_a+1$  for next sample gather

If  $S'_r(T_{d2}) < 0$ , scale  $j_a=j_a-1$  for next sample gather

**Step 5:** If  $t \geq T_m$ , Set  $j_a, d_a$ . Otherwise, increase  $d_a=d_a+1$

**Step 6:** If  $Y_a \leq 1$ , Keep  $Q1=Q3=1$  and

$Q2=Q4=0$

**Step 7:** Go to step 2 and repeat the process.

The aforesaid action is to utensil wavelet modulated technique and converted into a flow chart that is shown below in figure 3.

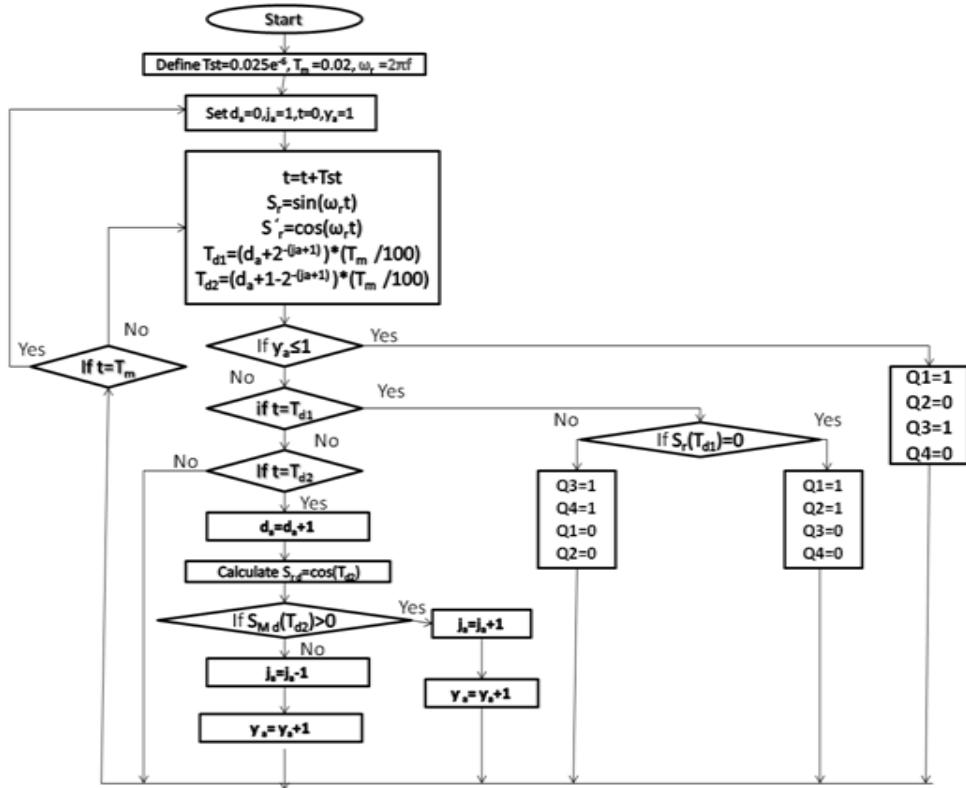


Figure 3: A Flowchart for an Algorithm to Implement the Wavelet Modulated Technique

## RESULTS AND DISCUSSIONS

The modulation technique proposed in the paper is coded using MATLAB and then it is activated with SIMULINK model. The performance when supplying R-L (linear load) with  $R=100\text{ohms}$ ;  $L=470\text{mH}$ .

- Single phase bridge inverter

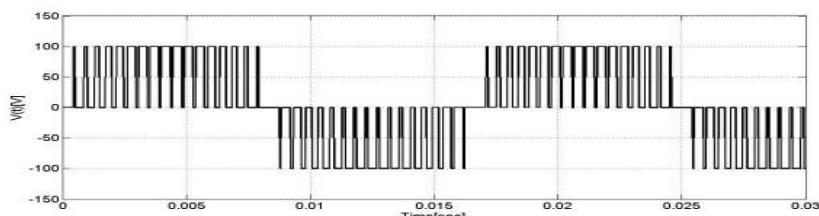


Figure 4: Simulation of Output Voltage Waveform For Single Phase Bridge Inverter

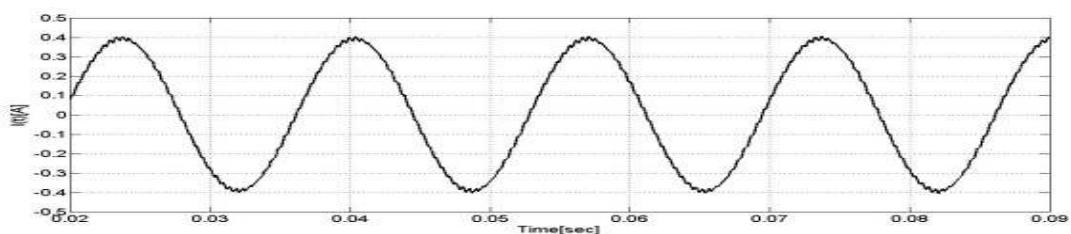
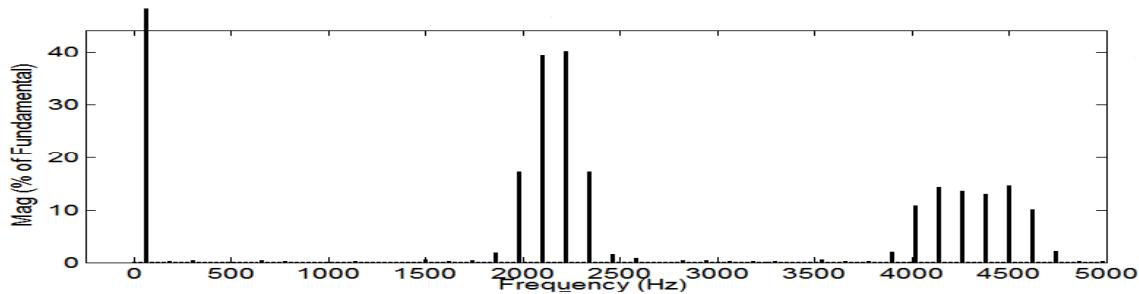
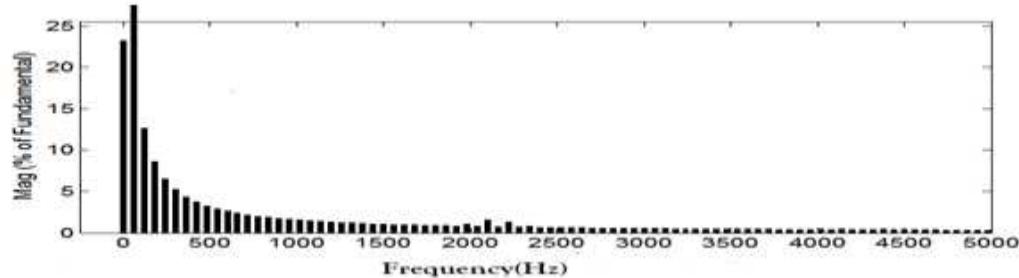


Figure 5: Output Current Waveform for Single Phase Bridge Inverter

Figure 6:  $\% \text{THD}_v = 68.99\%$ Figure 7:  $\% \text{THD}_i = 26.51\%$ 

- **Z-Source Inverter**

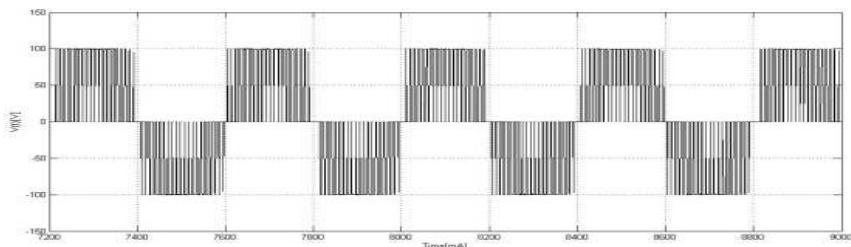


Figure 8: Output Voltage Waveform of Z-Source Inverter

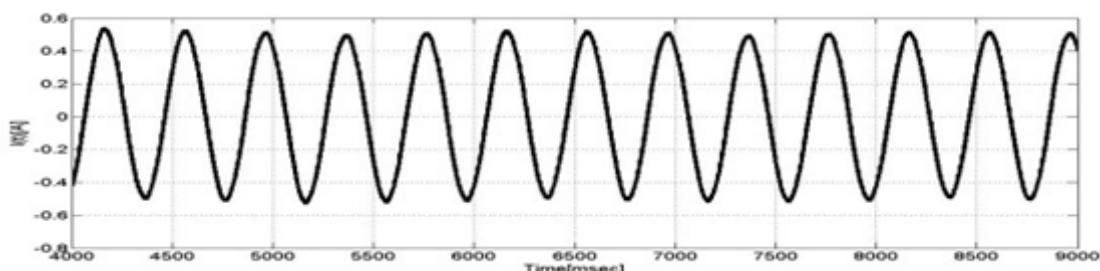
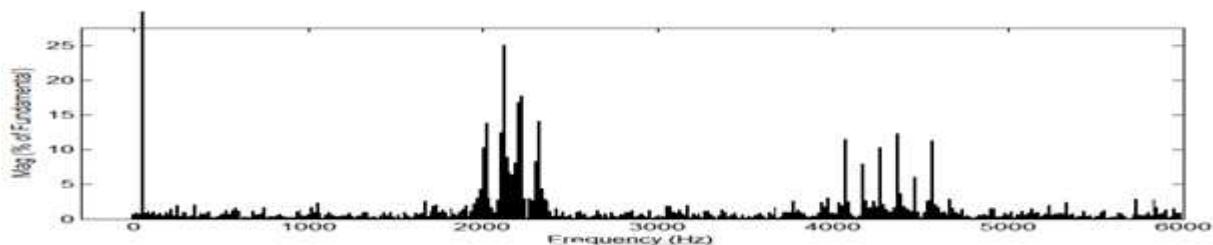
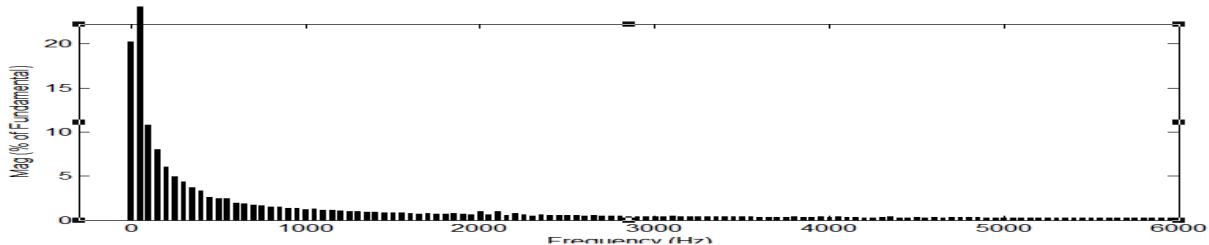


Figure 9: Output Current Waveform of Z-Source Inverter

Figure 10:  $\% \text{THD}_v = 57.20\%$

Figure 11:  $\% \text{THD}_i = 24.83\%$ 

- **Wavelet Modulated Inverter**

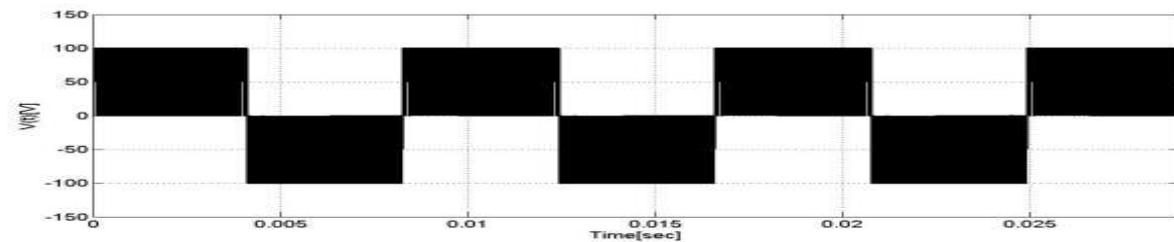


Figure 12: Output Voltage Waveform for Wavelet Modulated Inverter

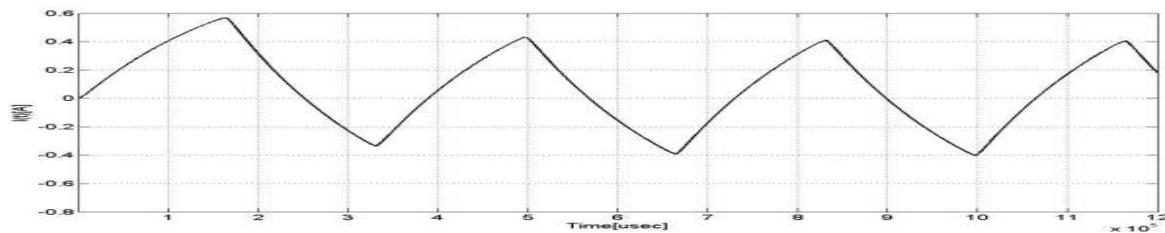
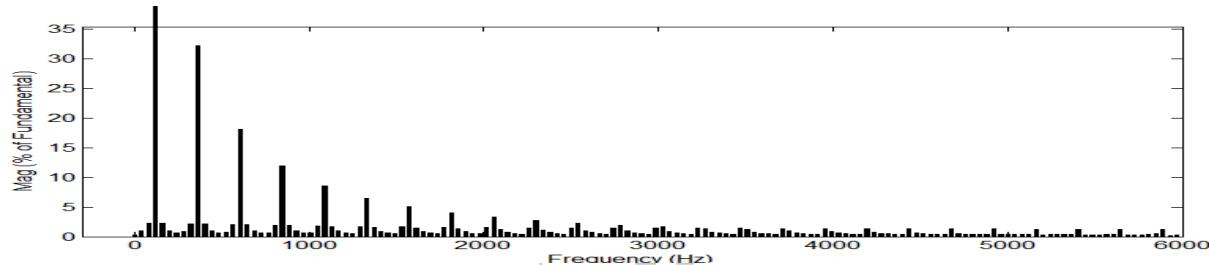
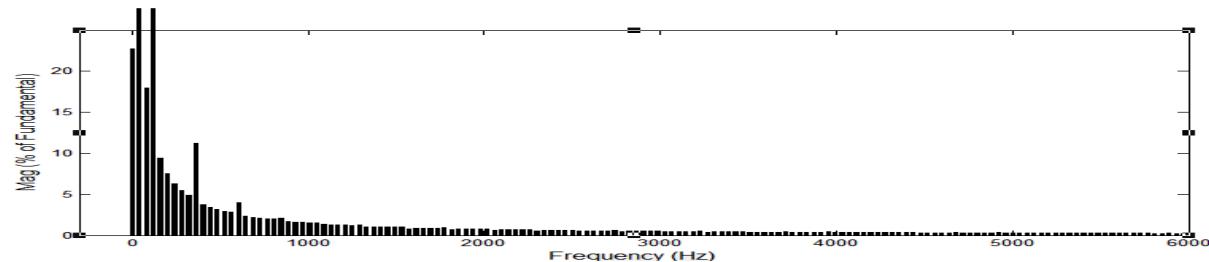


Figure 13: Output Current Waveform for Wavelet Modulated Inverter

Figure 14:  $\% \text{THD}_v = 42.62\%$ Figure 15:  $\% \text{THD}_i = 22.62\%$ 

- **Wavelet Modulated Z-Source Inverter**

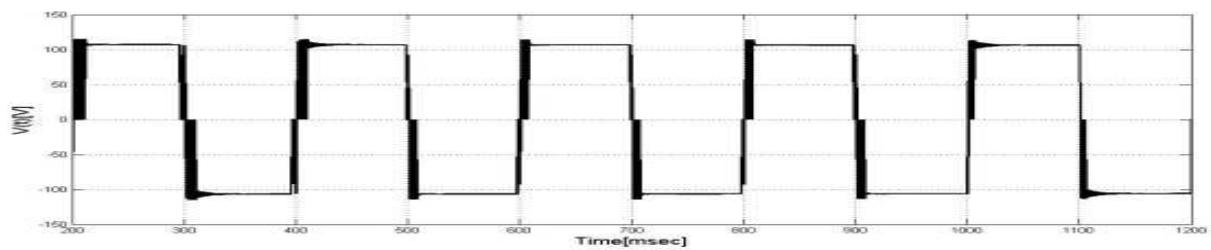


Figure 16: Output Voltage Waveform for Wavelet Modulated Z-Source Inverter

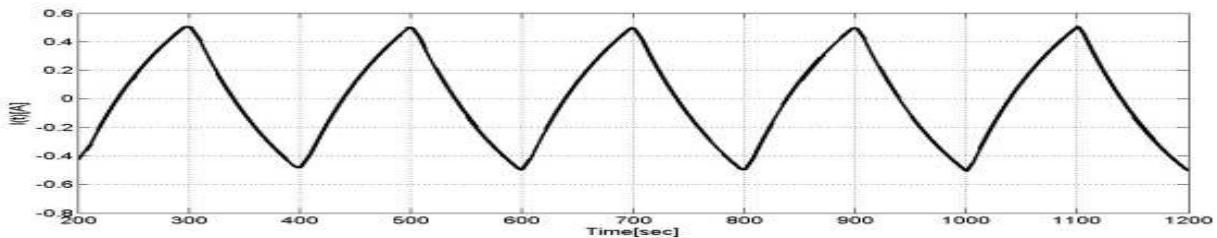


Figure 17: Output Current Waveform for Wavelet Modulated Z-Source Inverter

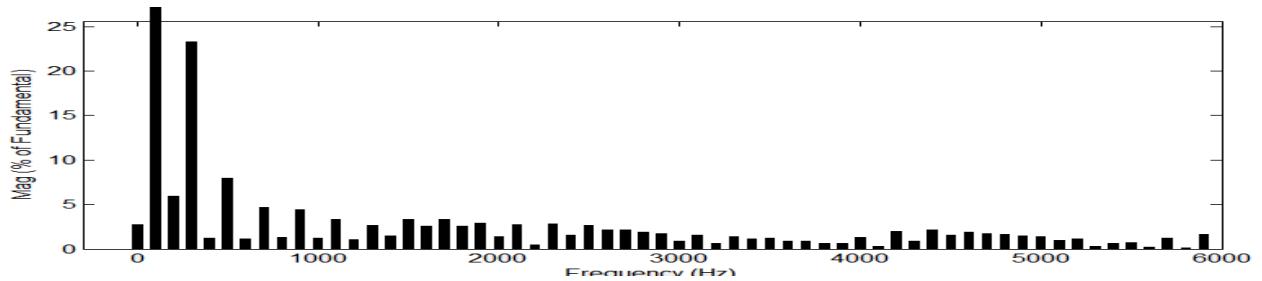


Figure 18: %THD<sub>v</sub> = 28.97%

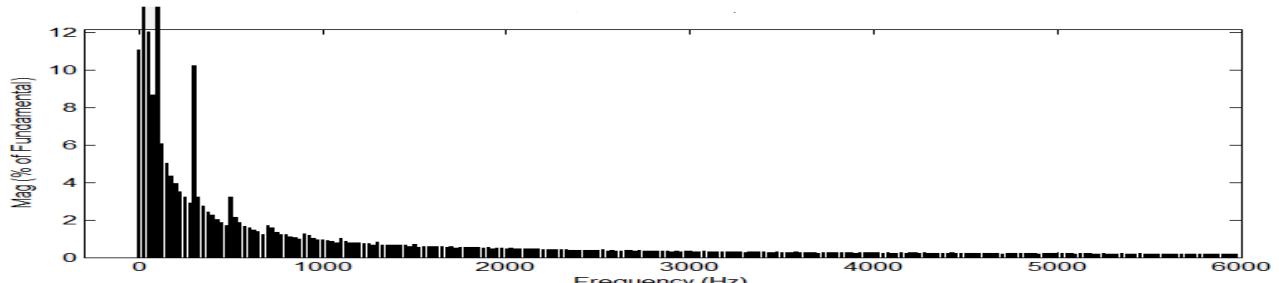


Figure 19: %THD<sub>i</sub> = 18.74%

Comparing of voltages, currents in different modulating techniques with R-L load(Linear Load)

Table 2: Voltage & Current Values

| Modulation Technique | Voltage (V) | Currents(A) |
|----------------------|-------------|-------------|
| PWM                  | 100         | 0.44        |
| ZPWM                 | 103         | 0.4         |
| WM                   | 100         | 0.4         |
| WZ                   | 110         | 0.5         |

Comparison of THD values for voltages, currents in different modulating schemes.

**Table 3: %THD for Different Modulated Scheme**

| Modulation Technique | %THD <sub>v</sub> | %THD <sub>i</sub> |
|----------------------|-------------------|-------------------|
| PWM                  | 68.99%            | 26.51%            |
| ZPWM                 | 57.20%            | 24.83%            |
| WM                   | 42.62%            | 22.62%            |
| WZ                   | 28.97%            | 18.74%            |

## CONCLUSIONS

In this paper, the approach is done through periodic altering of samples and employed to bring out new modulation technique. The basic concept is to construct altering of repeated sampling things and reconnect it to continuous time signal. An algorithm for the introduced wavelet modulated Z-Source inverter techniques has conducted and the performance contrast shows that wavelet modulated Z-Source gives a smoother output voltage, and lesser harmonic distortion.

## REFERENCES

1. S. A. Saleh, C. R. Moloney, and M. A. Rahman, “Development and testing of wavelet modulation for single-phase inverter’s”, IEEE Trans. Ind. Electron., vol. 56, no. 7, pp. 2588–2599, Jul. 2009.
2. S. A. Saleh, C. R. Moloney, and M. A. Rahman, “Analysis and development of wavelet modulation for three-phase voltage-source inverters”, IEEE Trans. Ind. Electron., vol. 58, no. 8, pp. 3330–3348, Jul. 2009.
3. S.A. Saleh, M. Azizur Rahman, “An introduction to wavelet modulated inverters”, IEEE Press Series on Power Engineering.
4. A. Aktaibi, M. A. Rahman, A. Razali, “A critical review of modulation techniques”, Proc. IEEE 12th DSP Conf., Jackson Lake Lodge, WY, pp. 544–549, Sep. 2006.
5. Poh Chiang Loh, D. Mahinda Vilathgamuwa, Yue Sen Lai, Geok Tin Chua and Yunwei Li, “Pulse-width Modulation of Z-Source Inverter”
6. S. A. Saleh, C. R. Moloney, and M. A. Rahman, “Developing a nondyadic MRAS for switching DC–AC inverters”, in Proc. IEEE 12th DSP Conf., Jackson Lake Lodge, WY, Sep. 2006, pp. 544–549.